White Oak Bayou: Benefits of a Restored Urban Stream

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Executive Summary

White Oak Bayou and its tributaries comprise more than 140 miles of streams covering the northwest side of Harris County. For much of the time since the lower portion of the Bayou was lined with concrete in the 1960s, White Oak has served the 400,000 people who call this watershed home primarily as a drainage conduit. Yet hidden beneath this concrete barrier, White Oak Bayou has the potential to improve economic prosperity, environmental vitality, and community health in this corner of Houston. This study estimates that, once removed of concrete and returned to a more natural state, White Oak Bayou has the potential to bring approximately $3 million annually to surrounding neighborhoods in recreational benefits, improved property values, and ecosystem services. This study, supported by the White Oak Bayou Association and funded by the Rice University Center for Civic Leadership, attempts to quantify the potential economic benefits of restoration in order to allow citizens and policy makers to make more informed decisions about the future of the Bayou.

To estimate the potential value of restoring White Oak Bayou, this study draws on interviews with Harris County Flood Control District (HCFCD) representatives, Houston-area spatial data, and highly-regarded studies in both ecology and economics. Real estate along two Houston bayous was mapped in order to determine the potential effect of restoration on residential property values. Additionally, HCFCD's maintenance expenditures on concrete lining in White Oak Bayou were investigated to estimate the value of maintenance reduction provided by a natural bayou. Finally, over 1,500 leisure science studies were assessed and compared with conditions in Houston in order to illustrate the value of possible recreation opportunities available along a newly restored White Oak Bayou. In addition to the three critical benefits mentioned above, a number of secondary ecosystem services were also evaluated using the estimates of previous research. This powerful combination of data sources was tailored to the unique characteristics of Houston and White Oak Bayou for the most accurate results possible.

Results indicate that restoration of White Oak Bayou could bring $2.9–$3.7 million dollars of benefits annually to Houston and its residents. The largest portion of this figure, some $1.9 million, is represented by tax revenues accrued from higher values for single family residential properties near the bayou. This conservative figure does not account for commercial and multifamily properties, so the potential total could be even larger. The investigation reveals that in the ten year period between 2005 and 2015, HCFCD spent more than $6.1 million on concrete maintenance projects in the White Oak Bayou watershed. This averages to $610,000 in yearly repair costs which could potentially be saved by restoration to a natural stream. In regards to recreation, previous studies indicate that boaters and fishers could expect to experience $560,000

to $1,000,000 in leisure benefits thanks to restoration of White Oak Bayou. Other environmental benefits, such as water filtration, soil formation, and biological regulation, are valued at $52,000 to $132,000 based on the experience of previous studies.

White Oak Bayou has the potential to contribute to social, environmental, and economic changes in Houston. Restoration has the potential to create increases in property values, opportunities for recreation, reduction of maintenance costs, and improvements in quality of life. Although these quantitative benefits are difficult to pin down, this study estimates a value in the range of $3 million annually. Although it remains to be seen whether this restoration will be feasible, given the City's current water management needs and the costs of concrete removal, the findings presented in this study provide additional context to help community members integrate White Oak Bayou into a more sustainable, prosperous, and healthy Houston.

Introduction

As cities have expanded, they have placed increasing pressures on the natural environments that sustain them. Because their social, environmental, and economic benefits have long been underestimated, urban streams are often sacrificed in order to provide for a city's stormwater and waste management needs. Many urban streams have suffered from significant pollution, and in some cases, even extinction as they are forced underground to make way for houses, highways, and businesses. One study estimated that, because of stream burial and diversion, 73 million Americans live in "urban stream deserts" where they have little or no access to these vital amenities (Napieralski 2016). Where they still survive, urban streams have often been dredged, straightened, or lined in concrete to protect and provide for local human activities. In general urban streams tend to suffer from loss of habitat, reduction of water quality, and drastic hydrological changes (Riley 1998: 99). As a result of rapid urban development, modern cities are now facing an "urban stream syndrome" crisis. Urban streams today have less biodiversity, are prone to 'flashier' floods, and have reduced nutrient uptake as a result of riparian deforestation and increased stormwater flows from urban catchment areas (Walsh et al. 2005).

In response to this phenomenon, new schools of thought have begun to reshape the way we think about stormwater management. Whereas historic methods attempted to move water away from developed areas as quickly as possible, urban planners are now suggesting that floodwaters should be absorbed and detained in urban landscapes. Known as Low Impact Development (LID), this philosophy promotes "green", or sustainable, infrastructure which utilizes natural processes, such as attenuation and infiltration of stormwater, as an alternative to overburdened drainage pathways. An effectively distributed network of parks, detention basins, pervious surfaces, and natural channels not only has the potential to reduce flooding, but also filter stormwater and provide aesthetically-pleasing green spaces for recreation and enjoyment during non-flood times (Shanley 2013).

Healthy urban streams can provide a number of useful services to city residents, from recreation opportunities, to wastewater management, to climate and pollution control. These public goods are known as "ecosystem services" because they are benefits which humans derive from the environment. Ecosystem services are vital to a city's daily functions, but they are often overlooked and their monetary value is difficult to account for in public debate. In 1997, Robert Costanza published a seminal article in *Nature* titled "The Value of the World's Ecosystems and Natural Capital." This article called attention to the irreplaceable value of the ecosystem services which the world's oceans, forests, wetlands, and rivers provide to humanity. In total, Costanza found, the Earth's biosphere produced between $16–54 trillion in benefits annually. Almost 20 years later, his work continues to be a guidepost in the field of ecological economics, and authors continue to rely on his estimates (Rosner 2009, Krieger 2001). In general, river ecosystems provide four broad types of services: (1) supporting services, such as nutrient recycling and stream formation, which allow the ecosystem to perpetuate itself and continue providing

benefits; (2) provisioning services, which generate products for use by humans, such as food, water, and raw materials; (3) regulating services, such as water filtration and carbon sequestration, which help to maintain resources used by humans and wildlife alike; and (4) cultural services, which provide indirect benefits in the form of recreational opportunities and aesthetic appeal (Millennium Ecosystem Assessment, 2005).

A growing body of literature emphasizes the value of ecosystem services. Numerous studies have documented the link between urban green spaces and increased real estate values, a theory known as the "proximity principle." The proximity principle argues that houses closer to environmental amenities will have higher property values. Studies have found that the proximity effect can increase property values by as much as 20% for houses adjacent to parks (Crompton 2001a), and is especially powerful in the case of streams and greenways which provide aesthetically pleasing views. One study estimated that the Barton Creek Greenbelt in Austin, Texas increased property values by 12–20% for properties both nearby and directly adjacent to the natural creek bed, totaling more than $13 million in property value benefits in houses across the local neighborhood (Crompton and Nicholls 2005). In addition to the proximity of greenspace creating benefits for property values, recent studies stress that the *type* of greenspace matters. Active recreation facilities meant for running, biking, and sports may create traffic and privacy problems, which can actually lower the values of immediately adjacent homes. On the other hand, passive recreation parks designed for strolling and picnicking tend to be more visually appealing and have the strongest positive effects (Crompton 2001b).

Many cities around the world, recognizing the value of natural greenspace, have already begun stream restoration projects. Cheong-Gye, a buried stream in Seoul, South Korea, was restored in 2005 and transformed into a park and tourist destination. The success of Cheong-Gye has inspired a flurry of similar projects in South Korea, where stream restoration is now considered an important tool for economic growth (Reis and Silva 2016). Other projects in the United States, both big and small, have proved that urban Americans strongly desire access to natural streams (See Table 1).

Studies of stream restoration have documented the value of these projects in a number of ways. One study, using a survey approach which asked respondents to rate the value of a potential stream restoration, found that surveyed Koreans were willing to pay $49–$56 per year to restore a concrete-encased stream to a more natural state (Bae 2011). Another study, also using a survey method, found that Baltimore residents were willing to pay $33–$58 per household per year for the added recreational and aesthetic benefits of a 0.25-mile stream restoration project (Kenney et al. 2012). By assigning a value to the potential benefits of stream restoration, the study determined that, from the community's perspective, the benefits outweighed the capital cost of restoration, resulting in a net profit. A third study along the South Platte River in Colorado using similar methods estimated the value of stream restoration at $21 per person (Loomis 2000).

These studies present a range of dollar values which reflect the range of factors affecting each project. However, it is clear that the common willingness to pay for stream restoration and its attendant benefits, multiplied across the hundreds of thousands of residents in an urban watershed, amounts to a significant economic value.

Table 1: Representative Stream Restoration Projects Worldwide, 2005–Present

Stream Name	Location	Length Restored	Cost	Year Completed	Benefits Realized
Cheong-Gye Stream	Seoul, South Korea	3.6 miles and 100 acres	$380 million	2005	Daylighted stream provides protection from 200 year flood, increases biodiversity by 600%, and generates $1.9 million in tourist activities
Los Angeles River	Los Angeles, California	11 miles and 719 acres	$1.3 billion	Proposed	N/A
Westside Creeks	San Antonio, Texas	14 miles	$79 million	Proposed	N/A
Las Positas Creek	Santa Barbara, California	2000 ft	$2.8 million	2010	Removed concrete lining to reconnect stream to floodplain. Stream can now absorb 10 year flood and mitigate 100 year flood by 50%.
Snakeden Branch and Tributaries	Reston, Virginia	26 miles and 359 acres	$70 million	In progress	Stabilized banks and restored natural stream channel. $10 million dollars in ecosystem services annually

White Oak Bayou: History of a Houston Waterway

White Oak Bayou flows through the heart of Houston, Texas. Originating in the northwest corner of the city, the stream touches many communities on its way to Downtown Houston, where it feeds Buffalo Bayou and eventually makes its way to the Gulf of Mexico. Approximately 9.5 miles of the White Oak Bayou channel, from its confluence with Cole Creek to the stream's end at Buffalo Bayou, are partially to completely lined in concrete. Where it is not encased in concrete, the Bayou has been deepened and stabilized, and generally lacks riffles, pools, and other features associated with natural streams. The riparian corridor is largely composed of grass-filled easements, and lacks the temperate forest characteristic of natural streams in the region. White Oak Bayou currently suffers from many hallmarks of the urban stream syndrome, but this was not always the case.

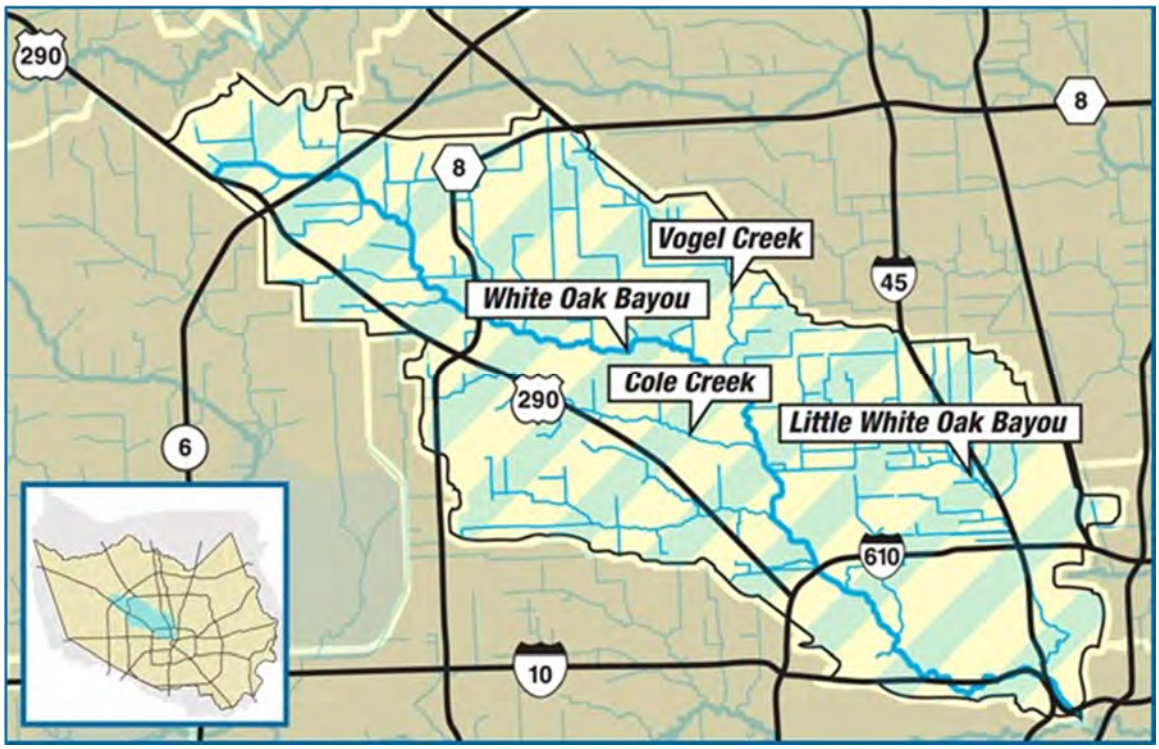
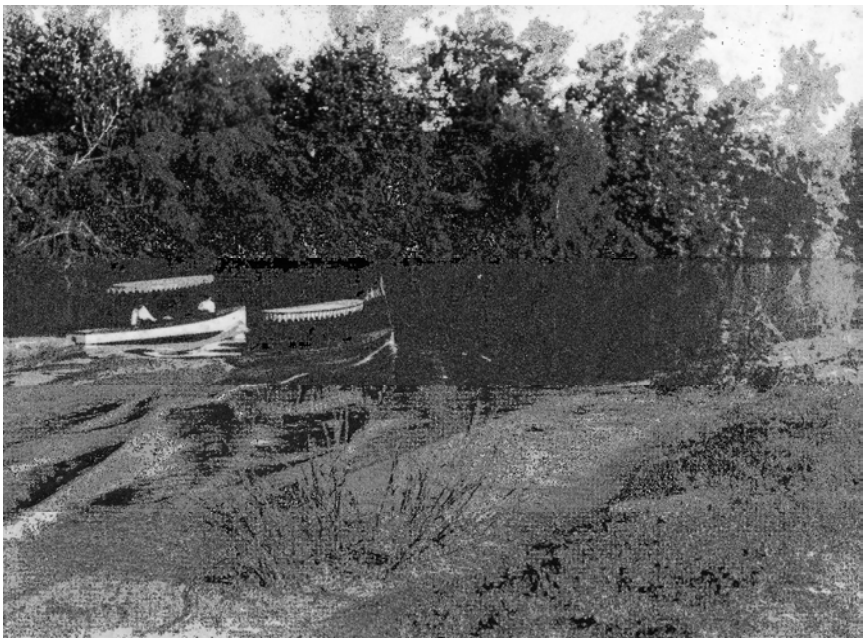


Image courtesy of HCFCD

White Oak Bayou has played an essential role in the history of Houston since the city's founding at the confluence of White Oak and Buffalo Bayous by John and Augustus Allen in 1836. The Allen brothers believed that the bayous would be able to transport ships to Houston and transform the sleepy town into a great trading emporium. Over the next one hundred years, parts of lower Buffalo Bayou were dredged, channelized, and cleared of vegetation to facilitate this vision. White Oak Bayou, however, remained relatively untouched. The banks of the slow flowing bayou were heavily wooded, and provided some small respite from the City's swampy atmosphere. Images from the early 20th century display the stream's extraordinary biological richness.

The image on the left shows White Oak Bayou circa 1900, courtesy of Rice Digital Scholarship Archive. The right image was taken in 1955, shortly before channelization, courtesy of HCFCD.

In its early history, White Oak Bayou provided a wealth of recreation opportunities to Houston residents. Shortly after the city was founded, Thomas Beauchamp established a hotel and saloon at a small spring along White Oak Bayou, close to modern-day Stude Park. Guests enjoyed Beauchamps Springs as a park, swimming hole, and source of fresh water until the early- to mid-20th century, when development and interstate highway construction eliminated the Springs (Kleiner).



Pleasure boating on Buffalo bayou. Image courtesy Rice Digital Scholarship Archives

Other attempts were made to capitalize on the recreational value of White Oak Bayou in the early 20th century. In 1903, to accompany the opening of its upscale development in the Woodland Heights neighborhood, the Houston Electric Company dammed Little White Oak Bayou near the modern intersection of White Oak Drive and Houston Avenue, and created Highland Park along the shores of the new lake. The park's numerous attractions, including a cafe, gun range, and water slide, led a Galveston newspaperman to praise it thusly:

> "Nestled between the hills fifty feet below the cafe and buffet building, with the rays of the sun glittering and sparkling upon its clear transparent surface is a lake of exceptional beauty and picturesqueness. Surrounding the lake on all sides are comfortable tree seats and rustic benches where the pleasure seekers, wishing to rest, may have ample opportunity [...] A few yards from the edge of the lake is an artesian well 478 feet deep, which has a flow of 75,000 gallons daily, furnishing patrons of the park with pure crystal mineral water [...] The surface of the lake, shining and glimmering in the moonlight, reflects the myriad electric lights, the pleasure boats with their gay occupants and the shadows of the great pine trees lend a touch of mystic enchantment to the scene." (Houstorian, 2009)

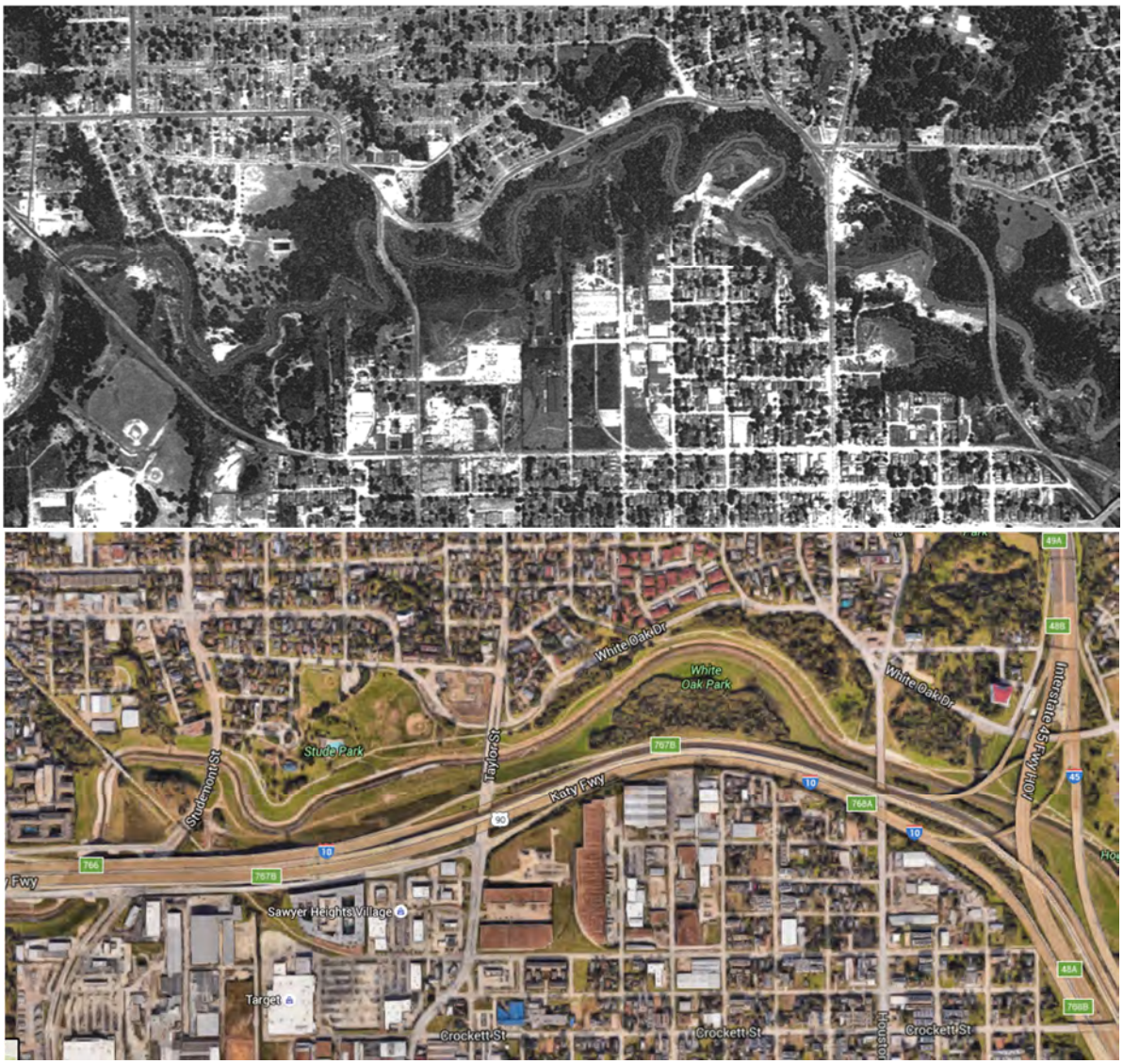
The lake at Highland Park along Little White Oak Bayou. Image courtesy Rice Digital Scholarship Archives

The lake at Highland Park along Little White Oak Bayou. Image courtesy Houstorian.com

Yet the waters of White Oak Bayou, which gave such joy to Houston pleasure seekers, also had deadly potential. In the first 100 years of the City's history, Houston suffered 16 major floods, some cresting at more than 40 feet above the banks (HCFCD 1998). Two particularly bad floods, which inundated Downtown Houston in 1929 and 1935, finally galvanized a local and federal response. The Harris County Flood Control District was founded in 1937, and with the help of the US Army Corps of Engineers, the District began altering the bayous to maximize their drainage potential. Stormwater management philosophy at the time called for channelization, a process in which the stream was widened, deepened, and lined with a layer of concrete, which stabilized the new streambanks and reduced friction with flowing water. This policy maximized the volume of floodwater carried by the stream, but unintentionally ignored the social, environmental, and economic benefits of a natural waterway. By 1950, the District had channelized 1,260 miles of streams in Harris County; Lower White Oak Bayou was significantly lined in concrete by 1971 (HCFCD 1998). These projects have protected Houstonians from many deadly floods but, as recent experience has proven, did not entirely eliminate the City's water management problems. Houston has continued to grow at rapid rates, increasing impervious ground cover and leading to larger stormwater runoff volumes moving through the same aging channel infrastructure. What at the time seemed like an appropriate management decision has, in hindsight, impaired valuable ecosystem services without completely alleviating Houston's drainage problems.

This image, taken in 1955 during the channelization of White Oak Bayou, bears witness to the extent of alterations made to the natural landscape. Image courtesy HCFCD

Channelization has proven to have a number of negative effects on White Oak Bayou's ecological health. The Bayou's natural water level has been greatly reduced; treated effluent, originating from Houston's wastewater treatment plants, comprises most of the stream's baseflow, and during flood events runoff from surrounding developments carries even more urban pollution into the stream. A 2007–2010 study found that White Oak Bayou was the most environmentally damaged stream in Harris County, with perilously small and undiversified communities of fish and invertebrates. The study concluded that "the worst type of channel design for support of native fish communities in Harris County streams is the historically-used, simple, straight-line, concrete-lined channel" which characterizes Lower White Oak Bayou today (Guillen and Oakley 2014). In light of these findings, citizens and policymakers have begun to search for solutions.



White Oak Bayou between Studemont Street and Houston Avenue, before and after channelization. The stream's course was straightened and most of the riparian vegetation corridor removed. Historic image courtesy of HCFCD, modern image courtesy of Google Earth.

In contrast to White Oak Bayou, Buffalo Bayou from Beltway 8 to Shepherd Drive has retained its natural appearance thanks to the dedicated efforts of Terry Hershey and the Bayou Preservation Association, whose lobbying efforts stopped the channelization of that stream in the 1960s. Buffalo Bayou presents an ideal case for what White Oak Bayou could have been, had the natural environment along the Bayou been preserved. Today, Buffalo Bayou is the centerpiece of a city-wide campaign to revitalize Houston's green spaces. This effort has been led by entrepreneurs and philanthropists who believe that greenspace and healthy, connected waterways can provide important social and economic benefits. This green revolution began with the renovation of Discovery Green, whose transformation from an asphalt parking lot in Downtown Houston to a public park and green space, has driven more than $1.2 billion in new construction,

a return on investment of more than ten-to-one (Hagstette 2016). The success of Discovery Green led, in 2012, to Houston's approval of the Bayou Greenways Initiative (BGI), which is in the process of adding more than 4,000 acres of parkland and 300 miles of trails along the City's bayous. One study found that BGI would generate more than $100 million dollars in medical, social, and environmental benefits (Crompton 2011). A similar study of Cypress Creek found that restoration there will add $14–20 million dollars in recreation and health benefits annually (Houston Parks Board). At the same time, Buffalo Bayou Park has undergone a multimillion dollar renovation to take advantage of the Bayou's natural beauty, and Memorial Park is scheduled for a similar remodeling (Hagstette 2016). The City's eager response to these projects demonstrates the immense value which greenspace could hold for the future of Houston.

White Oak Bayou has already benefited from this revolution, including BGI's installation of many miles of trails along the Bayou. A recent study observed many people using these trails for walking, running, and biking but could find almost no evidence of people passively enjoying the space or interacting with the stream (Shafer 2008). This suggests that as a greenspace, White Oak Bayou is still lacking in features which might attract picnickers, waders, or other passive park users. The literature suggests that naturalization will significantly improve ecosystem services and property value benefits, which together accounted for more than $28 million of the aforementioned BGI study's valuation. These services stand to benefit from the removal of concrete from White Oak Bayou. Although the type of stream restoration assumed in this report is unlike anything accomplished in Houston before, previous projects have proved the value of natural amenities for the City. Houstonians crave green spaces for recreation and relaxation, and the City's economy has responded eagerly to new natural amenities. Restoration of White Oak Bayou, if properly done using principles of fluvial geomorphology[1] along with LID techniques implemented throughout the watershed, could potentially provide numerous economic, social, and environmental benefits to the city with no adverse impact on the flood safety of families and businesses along the Bayou's banks. This study evaluates the economic potential of such a restoration.

Methods

A more natural White Oak Bayou has the potential to provide multiple additional ecosystem services, many of which are difficult to quantify in economic terms. This study evaluates those services most readily and reliably related to actual markets, focusing not on the one-time capital costs of restoration construction but on the potential long-term annual benefits of such a project. Because provisioning services along the bayou, such as timber and water provision, are negligible, this study focuses on the gains in regulating, supporting, and adding cultural services

[1] For further information on stream restoration refer to: Rosgen 1996, Applied River Morphology, Wildland Hydrology, Pagosa Springs, CO., 390 pp.

which will result from stream restoration. This study identified the four most valuable services which could be produced by a restored White Oak Bayou, and the methods used to determine them[2] are as follows:

1. **Stormwater Management**: White Oak Bayou's current stormwater management and flood control infrastructure must be maintained according to HCFCD standards in order to continue providing the same level of flood risk mitigation. Thus, this study assumes that there are feasible design options for a restored White Oak Bayou that would meet or exceed the Bayou's current level of flood mitigation. HCFCD maintenance expenses are investigated in order to determine the potential value of more natural stormwater management services provided by a restored White Oak Bayou that does not require concrete maintenance. This is known as a replacement cost analysis, because it uses the costs of an artificial substitute in order to evaluate an ecosystem service.

2. **Property Value**: Economists have documented a strong relationship between proximity to quality greenspace and property value. This study investigates residential property values along White Oak Bayou, compared to a nearby natural stream, to estimate the value of cultural and aesthetic services provided by the bayou. This is known as a revealed preferences analysis because it uses a market which is indirectly related to an ecosystem (in this case, real estate) in order to determine the value of that ecosystem for consumers.

3. **Recreation**: Ecosystem valuation studies use a variety of survey methods to determine the average consumer's willingness to pay (WTP) for the use or existence of a natural area. This value, often measured in dollars per person per day, is also known as consumer surplus, because it refers to the difference between what a consumer is willing to pay for a service and what they actually pay for that service (Loomis 2005). For many ecosystem services, and especially recreation, consumers often pay little or nothing to access opportunities from which they obtain great value and enjoyment. Consumers' WTP for recreation opportunities along a natural stream have been extensively documented by previous studies. This study aggregates and averages more than 1,500 of these studies in order to provide the probable value of recreation along a restored White Oak Bayou. This is known as a benefits transfer analysis, because it transfers the results of appropriate existing valuation studies to a new ecosystem. While not as powerful as more intensive methods, benefits transfer analysis allows for an effective and efficient estimation of the value of an ecosystem service. This per capita value is then translated to an overall annual value based on the current watershed population.

[2] For greater detail on ecosystem service valuation, see Pascual and Muradian, 2010. The methods used in this study, such as benefits transfer, direct market, and revealed preferences approaches were developed by The Economics of Ecosystems and Biodiversity (TEEB), an international body led by experts in sustainability and ecology.

4. **Other Ecosystem Services**: This study estimates the value of a variety of regulating and supporting ecosystem services using a secondary benefits transfer analysis, based on a prominent ecosystem services study (Costanza et al 1997). Also of value to this study is the work of de Groot et al. (2012), which aggregated more than 300 studies produced since Costanza's work was first published. These two studies provide estimations for the value of such services as soil formation, erosion prevention, and water filtration. These services, while unnoticed by most urban residents, have value through their ability to sustain ecosystems.

The evaluation methods used here are necessarily imperfect. Ecosystem services are not traded on open markets, and their true market value can never be assessed with total confidence. This study incorporates multiple strategies in order to provide the most comprehensive assessment to-date of the value of restoration along White Oak Bayou. The numbers presented in this study, while gleaned through estimation and assumption, nonetheless demonstrate the scale of potential benefits of restoration.

This study makes several assumptions about the proposed restoration of White Oak Bayou. From analysis of historical records, and from comparison observations of existing conditions along natural bayous in Harris County, it is assumed that the primary environment type along a naturalized White Oak Bayou will be forested riparian corridor. For simplification purposes, and because the full extent has yet to be determined, it is also assumed that restoration will include a minimum riparian corridor of 200 feet on either side of White Oak Bayou's current channel. Multiplying this 400-foot width by the approximately 9.5 channelized miles of Lower White Oak Bayou yields a restoration area of 460 acres. While the details of eventual naturalization will certainly vary, these estimates reflect a conservative estimate of future restoration efforts along White Oak Bayou.

Results

Stormwater Management

White Oak Bayou's current ability to move flood waters downstream at a high rate of conveyance and efficiency requires frequent, and at times costly, maintenance. The man-made channel of Lower White Oak Bayou was constructed by the US Army Corps of Engineers more than 40 years ago, and, as it ages, it requires frequent repairs. In order to minimize the Bayou's footprint while providing maximum storage, the Bayou's steep slopes require their current concrete anchors to prevent slumping and erosion. According to HCFCD engineers, hydrostatic bottom uplift necessitates periodic replacement of many portions of the concrete lining along the Bayou, which are also prone to damage from overbank erosion and debris collisions during flood events. Over the last five years, there have been two concrete repair projects in four locations along lower White Oak Bayou, as well as a series of projects along a major White Oak Bayou

tributary, Brickhouse Gully (also channelized), which have been completed in the last ten years. Details of these projects can be found in Appendix B (Hudson 2016). Because these costs represent repairs due to concrete degradation from daily and extreme event impacts, their costs are evaluated as a proxy for the value of White Oak Bayou's potential stormwater regulation services. Although a natural channel would also require periodic maintenance, the cost would be a fraction of that required for concrete replacement and servicing.

In the past ten years, HCFCD has spent at least $6 million to repair concrete stream channels in the White Oak Bayou watershed, averaging $610,000 per year. Over the course of these repair projects, HCFCD paid approximately $2,248 per linear foot of concrete lining along the main channel of White Oak Bayou, and $652 per foot along Brickhouse Gully[3].

Vegetation management costs along Lower White Oak Bayou, which includes turf establishment, mowing, herbicide application, and debris removal, amounted to $800,000 over the same five-year period in which HCFCD spent $3 million on channel maintenance. Management of natural stream banks comes with its own costs and problems, but is generally less expensive than concrete maintenance. Restoring White Oak Bayou to its natural state could save Houston taxpayers as much as $610,000 per year in eliminated or reduced concrete channel maintenance costs. In evaluating only one aspect of disturbance regulation, in this case stormwater management, this study may in fact underestimate the Bayou's potential value. A naturalized stream can also offer additional benefits such as drought mitigation and groundwater recharge, which are not accounted for in this study.

Recreation

Before channelization, Houstonians escaped the summer's heat by swimming, boating, and relaxing along the banks of White Oak Bayou. Restoration can provide the opportunity for some of these unique and valuable opportunities to return to the City. The greenspaces along White Oak Bayou currently provide an active recreation amenity; its trails are heavily used by walkers, bikers, and joggers, but provide little in the way of habitat or connection to nature. Indeed, a recent study of recreation activities along Buffalo and White Oak Bayous found that environmental health was a strong predictor of recreational use, with wooded banks being particularly crucial to drawing park users (Shafer et al 2013; 2008). National studies also find that passive recreation parks which include more natural space have a stronger effect on nearby property values and bring greater economic benefits (Crompton 2001b). The literature suggests that restoring the Bayou to a more natural state would beautify the park, bring in more park users, and significantly increase the value of neighboring properties.

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[3] These numbers were obtained from HCFCD, based on concrete maintenance projects the district has undertaken in the past ten years. Cost differentials are due to differences in the channel size and design; Brickhouse Gully is much narrower than White Oak Bayou and does not require the same scale of work. Further details can be found in Appendix B.

However, assessing the value of recreational activities can be a costly and time-intensive process. In lieu of large-scale survey methods, this report utilizes a benefits transfer analysis which relies on previous studies of other recreation sites to estimate the value of the canoeing, kayaking, and fishing services which would be available along a fully restored White Oak Bayou. Recreation opportunities available along White Oak Bayou will depend upon the nature and extent of restoration. Based on current conditions in Buffalo Bayou, it is estimated that restoration will provide opportunities for boating and fishing along White Oak Bayou; the value of swimming is also assessed, although it is much less likely to be possible due to external water quality issues.

Two recreation literature databases, one compiled by Oregon State University and the other by the Natural Resources Conservation Service of the United States Department of Agriculture, were identified for use in this study. These databases together contain more than 1,500 studies which use a variety of survey methods to determine the average consumer's willingness to pay (WTP) for the use of a natural area for recreation purposes. From the body of recreation evaluation literature, studies were selected which determined the value of fishing and non-motor boating activities. In the hopes that recreation will improve White Oak Bayou's water quality in the long term, the potential value of swimming was also evaluated. These studies were further refined based on activity, ecosystem, and location in order to filter down to those studies which most closely replicated the conditions and possibilities along White Oak Bayou. The result is three groups of studies: 11 on non-motorized boating (such as kayaking and canoeing), 53 on fishing, and 12 on swimming which together represent the best available data on recreation value in riparian environments. Details on the selection process and the results of the review are available in Appendix A.

Results indicate that the average recreation values Houston consumers can expect from a restored White Oak Bayou are $31 per boater per day and $57 per fisher per day. Swimming was valued at $21 per person per day, but because it seems unlikely to be possible in the near future, its value was not considered further. Even using these conservative estimates, it is clear that canoeing, kayaking, and fishing opportunities available along a restored White Oak Bayou would be of significant value to the city of Houston. One study observed 100 recreational users along natural stretches of Buffalo Bayou over two separate survey events (Shafer et al. 2008). Extrapolating from these results and ignoring seasonal variations, a very conservative estimate might find that 50 additional recreational users could be drawn to a restored White Oak Bayou every day. Multiplying these 50 users by the 365 days in a year and the $31 and $57 per captia use values for boating and fishing, it is estimated that Houstonians could derive an annual recreational benefit of $566,000 to $1,054,000 depending on which activities they engage in. As the stream recovers and its reputation improves in the Houston area, its recreational use will likely increase in value.

Property Value

Beyond the immediate value of regulating and providing various goods and services for human consumption, ecosystems also have significant intangible value as aesthetically-pleasing spaces which bring cultural, physical, and spiritual enjoyment to their users. The bayous, for example, are emblematic of Houston, and their environmental quality speaks to the aspirations and identity of the City. These environmental services are among the most difficult to quantify, but arguably also some of the most valuable to the long-term health of a community. There are some by-products of cultural and aesthetic services, however, that are easier to quantify. The aesthetic and atmospheric value of a natural space is often reflected in the value of neighboring properties, which may be worth more or less depending on the appeal which the ecosystem provides. This study used the value of single family residential[4] properties nearby Houston's bayous as an indicator of the effect of natural spaces on real estate.

Using Geographic Information System (GIS) software and the most recently available 2015 data from the Harris County Appraisal District (HCAD), this study compared the values of single family residential properties within one mile of Buffalo and White Oak Bayous. The comparison between White Oak and Buffalo bayous was chosen to illustrate the different effects which natural and channelized stream spaces have on nearby property values. Three buffers were drawn around the bayous, at 0.25-, 0.5-, and 1-mile distances from the channel centerline. These buffers were chosen to reflect the basic proximity principle assumption that properties closer to a natural amenity, like the Bayou, will have greater value. Means were then taken of the total market value of houses within each band, in order to determine broad trends in the data. See Appendix C for graphics of the results.

The most obvious difference between property values within the buffer zones in the two watersheds is that residential properties along Buffalo Bayou appear to be more valuable than those along White Oak Bayou. This could be due to a number of factors, including Buffalo Bayou's proximity to Downtown, the Museum District, and to a historically affluent neighborhood. However, the siting of these more active and affluent areas was likely also driven by proximity to the Bayou and thus is not necessarily an independent variable.

[4]Single family residential properties were chosen because they represent a larger and more consistent dataset than either multifamily or commercial properties, especially in the White Oak Bayou watershed. For similar reasons, the value of single family residential properties is a commonly accepted unit of analysis in the literature (Crompton and Nicholls 2005, Pascual and Muradian 2010).

Table 2: Comparison of Property Values for White Oak and Buffalo Bayous

Distance from Bayou (mi)	Average House Value, White Oak Bayou	Average House Value, Buffalo Bayou
0.25	258,713	1,096,450
0.5	280,872	958,954
1.0	251,062	826,811

In addition, this study examined how property values change in relation to proximity to both streams. In the case of Buffalo Bayou, property values fall as distance from the bayou increases, at a rate of about $100,000 per buffer zone. This finding suggests that a natural waterway could be a significant green amenity for which families are willing to pay more to access. However, the same pattern was not found in the White Oak Bayou neighborhoods. Residential properties along the total length of the Bayou do not appear to increase in value as proximity to the Bayou decreases. In fact, the converse relationship was found: houses that are 0.5 miles from the bayou are on average worth $20,000 more than those 0.25 miles from White Oak Bayou.

This view, however, obscures variation within the White Oak Bayou watershed. At the Bayou's confluence with one of its major tributaries, Cole Creek, at the intersection of Tidwell Road and TC Jester Boulevard, the concrete lining largely ends. Above this point, White Oak Bayou, though straightened and dredged, more closely resembles the natural stream it once was. When the geospatial buffers are divided at this point and the analyses are rerun, it becomes apparent and the concrete-free portion of White Oak Bayou replicates the property value pattern of Buffalo Bayou, in which proximity to the natural stream is associated with higher residential property value. In the lower, channelized portion of the Bayou, property values are generally higher but not obviously correlated with distance to White Oak. This suggests that restoration of White Oak Bayou could contribute beneficially to the value of the many residential properties along Lower White Oak Bayou.

Table 3: Comparison of Property Values for North and South White Oak Bayou

Distance from Bayou (mi)	Average House Value, North White Oak Bayou (Natural)	Average House Value, South White Oak Bayou (Concrete)
0.25	188,363	397,801
0.5	185,497	411,038
1.0	166,055	397,044

For more quantitative results, this study replicates the methods used to estimate the value of the Bayou Greenways Initiative (Crompton 2011). Researchers agree that proximity to natural parks can increase property values by as much 20%. This study samples single family residential properties within 600 feet (approximately three blocks) of White Oak Bayou, and applies a conservative premium of 5% property value increase due to restoration of the Bayou. Results indicate that restoration could have a net effect of almost $100 million on the property values of the 8,000 homes adjacent to White Oak Bayou. Taxed at a rate of 2%, the historic norm for Houston, this increase in property value could generate nearly $2 million in revenues to local government annually.

Table 4: Increases in Value for Properties along White Oak Bayou

Proximity/ Increase	Number of Homes	Average Value (2015)	Total Value (2015)	Average Value after Restoration	Total Value added by Restoration	Annual Tax Revenue Increases
Within 600 ft, at 5% increase	8,090	236,363	1,912,175,573	248,181	95,608,779	1,912,176
Within 1 mile, at 1% increase	101,203	266,102	26,930,368,022	268,763	269,303,680	5,386,074

It is likely that the benefits of restoration will extend beyond the immediate vicinity of White Oak Bayou. To reflect this theory, the results of a 1% increase in all property values within a mile of White Oak Bayou were also calculated. These results indicate that even marginal increases in property values, when spread across the many thousands of homes in the White Oak Bayou watershed, result in significant benefit to individual residents and to the City as a whole. Property value increases represent one of the largest and most tangible components of ecosystem services.

Other Ecosystem Services

Gas and Climate Regulation

Trees play an important role in climate regulation, both as sinks for greenhouse gases like carbon dioxide and for their ability to reduce local temperatures. A restored White Oak Bayou will provide habitat for many trees, as well as grasses and shrubs which fulfill similar regulatory processes. Riparian vegetation will reduce mowing requirements currently undertaken by HCFCD, saving taxpayer money and improving local air quality. Restoration is anticipated to produce $26,000-$32,000 in climate regulation services through increased tree canopy. This number is based on Costanza's estimates of the value of temperate forests' climate regulation at $57 per acre in 2015 dollars (a number which may be as high as $70) multiplied across the 460 acres of potentially restored floodplain.

Sediment Retention

Costanza limits his estimation of soil retention services to tropical forests, and estimates no value of these services in temperate forests of the type found along Houston's bayous. These services may not be required, as the current concrete lining prevents bank or bed erosion in Lower White Oak Bayou. Nonetheless, some sediment material does make its way downstream to Buffalo Bayou, from overland runoff and upstream unlined portions of the bayou, where it contributes to siltation of the concrete channel and, eventually, Buffalo Bayou and the Houston Ship Channel further downstream. The port requires frequent dredging to maintain its 40 foot depth, operations which cost the Port of Houston Authority between $40 and 50 million annually (Collier 2014). The ability of a naturalized stream to better regulate sediment flux on a daily basis can incrementally contribute to reducing these costs. De Groot values this service at $2.31/acre, amounting to $1,061 per year in erosion control benefits.

Soil Formation

The accumulation of dead leaves and other biomatter in forest ecosystems allows for the formation of valuable, nutrient rich soil. While de Groot does not assign a value to this service, Costanza estimates the value of forest soil formation at $6.47 per acre which, when multiplied across 460 potentially restored acres of riparian corridor along White Oak Bayou, yields an annual benefit of $2,977.

Nutrient Cycling

Forest ecosystems play an important role in cycling a variety of nutrients, including nitrogen, which is vital for plant growth. While Costanza does not attribute temperate forests a value for this service, de Groot estimates it $43 per acre. When multiplied across 460 acres of restored riparian forest, this gives a value of $19,700 per year in nutrient cycling.

Waste Treatment

Natural ecosystems are remarkably resilient, and some are able to filter out relatively high loads of waste and pollutants. A more natural bayou will be able to not only convey urban runoff away from city streets, but also trap a more significant amount of pollutants, thereby contributing to enhanced stormwater quality as storm discharges leave the city. Constanza estimates this service at $56 per acre, and de Groot at $3.24 per acre. Although not totally negating the need for upstream stormwater quality control, the total value for stormwater pollutant treatment along White Oak Bayou could amount to between $1,490 and $25,900 annually.

Biological Control

When natural ecosystems are limited in size, as they are in urban areas, they often cannot support adequate populations of animals and plants to maintain natural cycles. Biological control refers to an ecosystem's ability to perform these functions and perpetuate itself, often in the form of predator-prey relations and other regulatory processes. Falling foliage from overhanging trees, for example, contributes nutrient to streams which are vital for fish populations. Currently, the floodplain area around the concrete portions of White Oak Bayou is highly developed. The linear greenspaces that do exist along the Bayou are highly manicured and lacking in forested canopy or stream access, potentially limiting the health of animal populations in and around the Bayou (Guillen and Oakley 2014). Restoration of White Oak Bayou would likely result in the rehabilitation of a riparian forest ecosystem with the ability to better regulate various animal populations. Constanza estimates this service at $2.59 per acre, and de Groot at $107 per acre. The total value of biological control along White Oak Bayou could amount to between $1,190 and $50,000 annually.

Discussion:

This study has shown that a restored White Oak Bayou has the potential to provide a number of valuable ecosystem services. Increases in property values linked to aesthetic and cultural services provided by the Bayou are the most substantial benefits of restoration. Analysis of housing patterns along White Oak and Buffalo Bayous indicate that proximity to natural waterway may be associated with higher home values, while proximity to concrete-lined reaches of White Oak Bayou could limit this effect. However, it is important to note at that correlation does not imply causation. The value of a house is influenced by a complex array of variables, of which natural space proximity is just one. The analysis presented above is not conclusive, but it does add evidence-based weight to the common sense intuition that natural streams contribute to a city’s economic prosperity. Previous studies indicate that natural parklands can increase neighboring house values by as much as 5%, resulting in an average increase of almost $12,000 for homes along White Oak Bayou. These benefits will accrue not just to households along the bayou, but also to all Houstonians through increases in property taxes amounting to a potential $1.9 million annually. Although this number is a rough estimate, it may in fact underestimate the total value

of restoration, because it does not count for likely benefits experienced by commercial and multifamily properties along White Oak Bayou.

Investigation revealed that continued use of White Oak Bayou as a concrete-lined drainage way is not without its costs. In the last ten years, HCFCD has spent more than $6 million to repair concrete surfaces in the White Oak Bayou watershed. Healthy ecosystems are remarkably resilient and self-restorative, and if White Oak Bayou were restored using sustainable techniques, it could potentially handle similar stormwater levels without the need for expensive repairs. Regulation of stormwater by natural processes has the potential to save Houston taxpayers money, and free up HCFCD resources to provide other valuable services. The restored Bayou's ability to naturally manage stormwater was the next most valuable service, being valued at $610,000 annually.

A restored bayou can also offer additional recreation opportunities to Houston residents, as it once did in the City's early history. Numerous scientific studies have estimated the value of these activities for consumers. This study evaluated and aggregated more than 1,500 such studies in order to estimate the value of boating, and fishing per person per day as $31 and $57 respectively. Even if only 50 people engage in these activities along White Oak Bayou every day as a result of restoration, they would provide between $400,000 and $1 million in value annual. Of course, recreation opportunities will depend on the extent of restoration. Many Houston-area streams, including White Oak Bayou, are currently classified as Impaired by the Texas Commission on Environmental Quality because of poor water quality conditions which make them unsafe for direct contact with humans (Shafer 2008). This study assumed that water quality improvement, to a level acceptable for swimming and/or consumption, would require a much more extensive effort beyond stream restoration. Thus recreation value analysis is limited to those activities already present on other natural, but similarly impaired, streams in the area. This study also does not evaluate the potential enjoyment which other recreational users, such as hikers, bikers, and joggers, might receive from a restored stream. For these reasons, recreational value of a restored White Oak Bayou is valued at $560,000 to $1 million annually.

White Oak Bayou also has the potential to provide a number of other ecosystem services such as nutrient cycling, soil formation, and climate regulation. Although these services are often invisible to the average city resident, they still hold value for their ability to improve and sustain the environment in which we live, thus supporting the continued supply of other ecosystem services. Based on previous studies, these various ecosystem services are valued at between $26,000 and $132,000 dollars.

The value of White Oak Bayou will ultimately be conditional on the extent and scale of restoration. All of the estimations presented by this study are dependent on the type, size, and quality of natural habitat created by restoration. Assumptions about the final results are kept

conservative so as not to inflate the potential value of restoration. The scale of restoration, for example, is assumed to be limited to the concrete-lined stretch of Lower White Oak Bayou, although the channelized northern reach of the stream could also benefit from habitat improvement. Regardless of the extent of restoration, the evidence presented here indicates that any improvement in ecosystem quality can result in many benefits to Houston in the form of property values, stormwater management, and recreation opportunities.

This study was restricted in its scope by time, skill, and manpower limitations. Most of the estimates presented here were obtained through benefits transfer analyses relying on the work of previous researchers. While effective and efficient, this method lacks the power and specificity of projects which gather unique on-site data. Once restoration options become better defined, it is recommended that more intensive surveys are conducted in order to assess how much residents are willing to pay for the ecosystem services which the Bayou might offer, and to better understand the specific benefits achievable through restoration options. A revealed preferences analysis using either surveys of local residents or statistical models of local housing markets will yield valid results more specific to the White Oak Bayou area. Such studies require greater resources and expertise, but will allow Houstonians to more effectively weigh the costs and benefits of restoration.

Conclusion

This study reveals that a restored White Oak Bayou has the potential to offer between $2.9 and $3.7 million in ecosystem service benefits annually. Almost $2 million of that total value stems from greater property values and attendant increases in tax revenues caused by the restoration of the bayou ecosystem, which are likely to increase beyond this level over time on their own. The Bayou's ability to naturally regulate stormwater could also save Houston taxpayers approximately $600,000 annually, which could be re-appropriated to other flood control efforts such as land acquisition and construction of additional detention, while new recreation opportunities along the Bayou could be worth as much as $1 million. Other ecosystem services, such as erosion prevention, nutrient cycling, and pollution filtration could be worth an additional $100,000 for their ability to maintain a pristine natural environment. The results are summarized below:

Table 5: Summary of Ecosystem Services

Ecosystem Service	Low Estimate	Only Estimate	High Estimate
Stormwater Management	--	$610,000	--
Recreation	$398,763	--	$1,053,938
Property Values	--	$1,912,176	--
Other Ecosystem Services (Climate Regulation, Nutrient Cycling, etc)	$52,716	--	$132,107
Total	**$2,973,654**	--	**$3,708,220**

This study, in evaluating a hypothetical future ecosystem, has attempted to quantify the unquantifiable. The numbers presented here should not be understood as hard data, but as sketches which outline the intrinsic and intangible worth of a restored White Oak Bayou. It remains to be seen what the costs and extent of stream restoration will be, and the degree to which restoration is feasible given the flood safety needs of the surrounding community. The estimates presented here are meant to serve as a rough guide for citizens and policymakers weighing the abstract value of an environment against the very real demands of city residents and infrastructure. It is hoped that they will provide a foundation for better understanding of the benefits and options of White Oak Bayou's future.

Appendix A

Recreation Value Studies

In order to assess the value of recreation services along a restored White Oak Bayou, this report drew from a number of previous studies collected in two databases: the Recreation Use Values Database for North America (RUVDNA), developed by Dr. Randall Rosenberger at Oregon State University; and a database compiled by the Natural Resources Conservation Service (NCRS) of the United States Department of Agriculture. Together these studies compile more than 1500 recreation use value estimates. The process of refining this huge database to find studies relevant to the case of White Oak Bayou is described below:

- First, the databases were refined to only select studies for relevant activities: swimming, fishing, and non-motor boating, known in both studies under the category floating/rafting/canoeing. In the case of RUVDNA, fishing studies were able to be refined further to include only freshwater fishing, and boating service were able to be refined to exclude whitewater rafting or kayaking.
- The NCRS database carried information about the relative development of infrastructure near the recreation site. Studies from this database were refined to exclude rural and primitive development (ROSCLASS 1–6). Unfortunately, this information was not available for RUVDNA studies.
- Next, the resulting group of studies was refined by primary ecosystem type. Fishing studies were limited to river environments only. The number of swimming and boating studies available was more limited, so different criteria were applied. Studies were accepted if they came from riverine or forest ecosystems. Care was taken to exclude strictly oceanic studies.
- Many studies in the databases presented a range of values for the recreation service which they evaluated. So as not to inflate the results of this report, the lowest possible value was selected from each study.
- Finally, study estimates were adjusted for inflation. RUVDNA presented estimates in 2010 dollars, NCRS in 2004 dollars. Both sets of estimates were adjusted to 2015 dollars.

The below tables present details of the studies evaluated for this report:

Table A.1 - Studies on the Value of Recreational Swimming:

Study Year	Location of Study	Value of Swimming ($ per person per day)
1968	Texas	25.23
1969	New York	52.2
1982	Lake Carlsbad Recreation Area	9.3
1982	Flathead River, Montana	12.54
1988	Sacramento River, California	33.41
1990	United States	18.66
1991	United States	30.92
1996	United States	7.6
1999	Lake Erie, Ohio	20.89
2002	Peconic Estuary, New York	13.36
2003	Texas	11.23
2005	Snake River	26.88
Average:		21.85

Table A.2 – Studies on the Value of Recreational Boating:

Study Year	Location of Study	Value of Boating ($ per person per day)
1991	Boundary Waters, Montana	8.63
1999	Minnesota River, Minnesota	42.39
1984	Upper Delaware River, Delaware	10.58
2004	North Carolina	37.13
1980	Colorado	39.77
1991	United States	26.43
1982	Salt River, Arizona	5.14
1988	Louisiana	45.35
1998	Trinity River, California	31.63
1996	United States	40.54
1977	Idaho	53.52
Average:		31.01

Table A.3 – Studies on the Value of Recreational Fishing:

Study Year	Location of Study	Value of Fishing ($ per person per day)
1998	USA	40.42
1979	Columbia River, Washington	93.73
1983	St. Lawrence River, New York	108.26
2004	Roanoke River, North Carolina	26.43
1986	Idaho	35.00
1998	Trinity River, California	2.06
1994	Alberta, Canada	2.52
1985	Adirondacks Region, New York	93.43
1991	Maine	16.48
1998	North Dakota	49.09
2004	New River State Park, Virginia	15.11
1983	Maine	13.33
1990	Feather River, California	50.37
1993	Seymour River, British Columbia	0.91
1993	Pennsylvania	32.25
2001	Pennsylvania	176.72
1989	Wisconsin	20.37
1993	Mountain Fork River, Oklahoma	52.09
2006	Arkansas	27.10
2005	Cheat River, West Virginia	6.06
2003	Tennessee	10.12
2000	North Carolina	413.67
1977	Salmon River, Idaho	17.85
1980	Colorado	38.28
1981	Cache la Poudre River, Colorado	103.82
1983	Oregon	36.97
1985	Idaho	25.05
1985	Fort Apache Indian Reservation, Arizona	74.00
1985	Colorado River, Arizona	89.07
1986	Idaho	35.10
1987	Montana	101.56
1987	Colorado River, Arizona	67.37

Study Year	Location of Study	Value of Fishing ($ per person per day)
1992	Montana	93.36
1993	Taylor River, Colorado	55.52
1999	Copper River, Arkansas	30.95
1985	Oregon	33.32
1986	Oregon and Washington	22.81
1970	Cache la Poudre River, Colorado	7.83
1980	Fort Apache Indian Reservation, Arizona	16.20
1996	Gurkana River, Arkansas	24.49
2005	Idaho and Wyoming	14.23
1982	Flathead River, Montana	15.46
1988	Montana	54.62
1993	Laramie River, Wyoming	12.48
2006	Snake River, Wyoming	10.23
2002	Montana	10.66
2000	Henry's Fork, Idaho	240.64
2001	Alaska	100.83
1989	Sacramento River, California	131.91
2005	Willow Creek, Arkansas	49.44
1983	St. Lawrence River, New York	131.12
1986	Idaho	29.52
1990	Missouri River, Montana	100.40
Average:		57.75

Appendix B

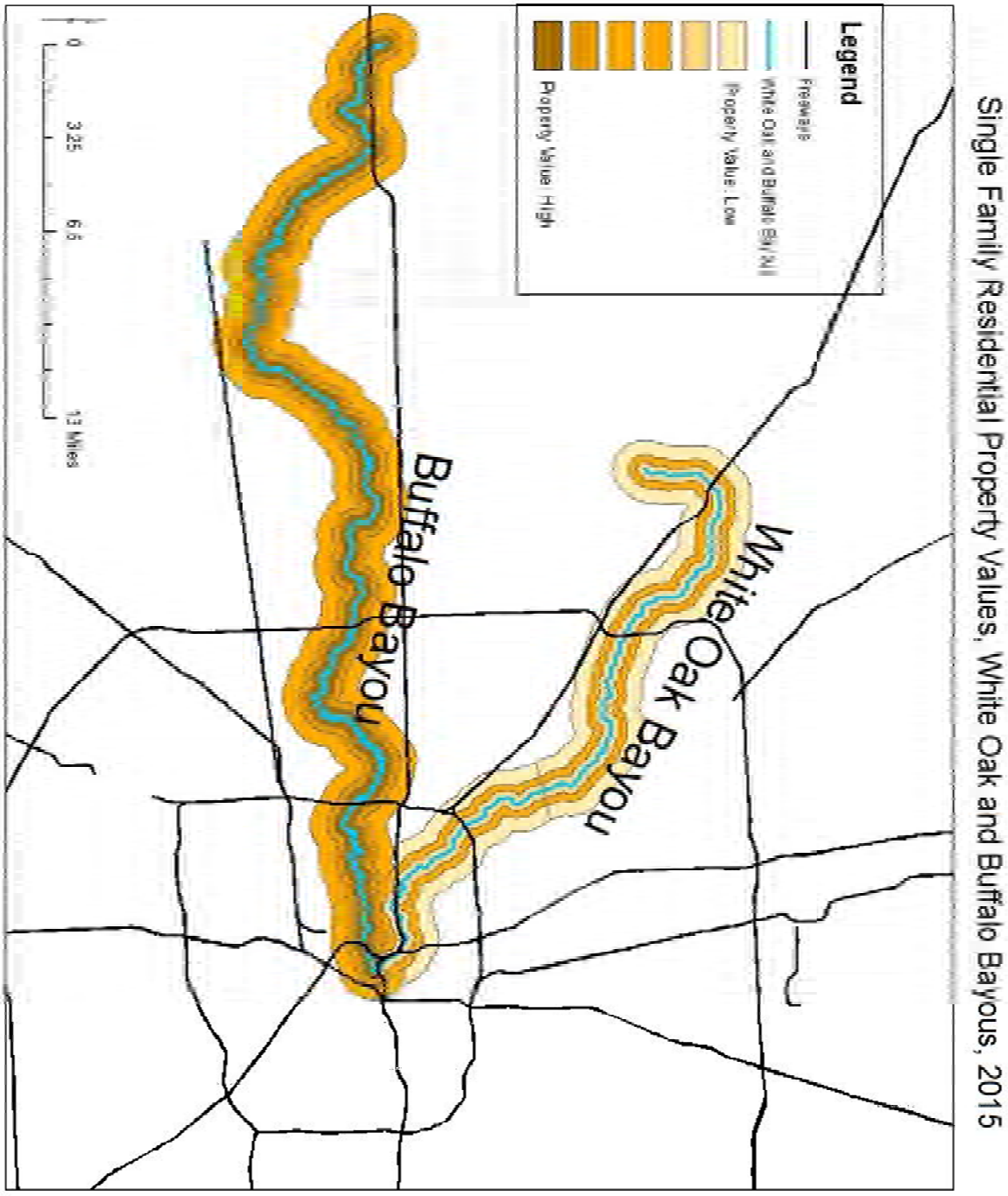
Table B.1 - Maintenance Projects along White Oak Bayou and Tributaries

Year of Project	Stream	Site	Length (Feet)	Construction Cost
2006	Brickhouse Gully	Confluence to Watonga Blvd	1400	$891,000
2011	Brickhouse Gully	BNSF Railroad to Magnum Rd	1100	$673,000
2012	Brickhouse Gully	Magnum Rd to Costa Rica Rd	2200	$1,500,000
	Total		4700	$3,064,000
2012	Lower White Oak Bayou	D/S TC Jester Blvd.	358	$1,575,968
		U/S Studemont St.	426	
2013	Lower White Oak Bayou	U/S IH-10	292	$1,449,536
		U/S Taylor St.	270	
Total			**1346**	**$3,035,054**
Grand Total			**6046**	**$6,099,054**

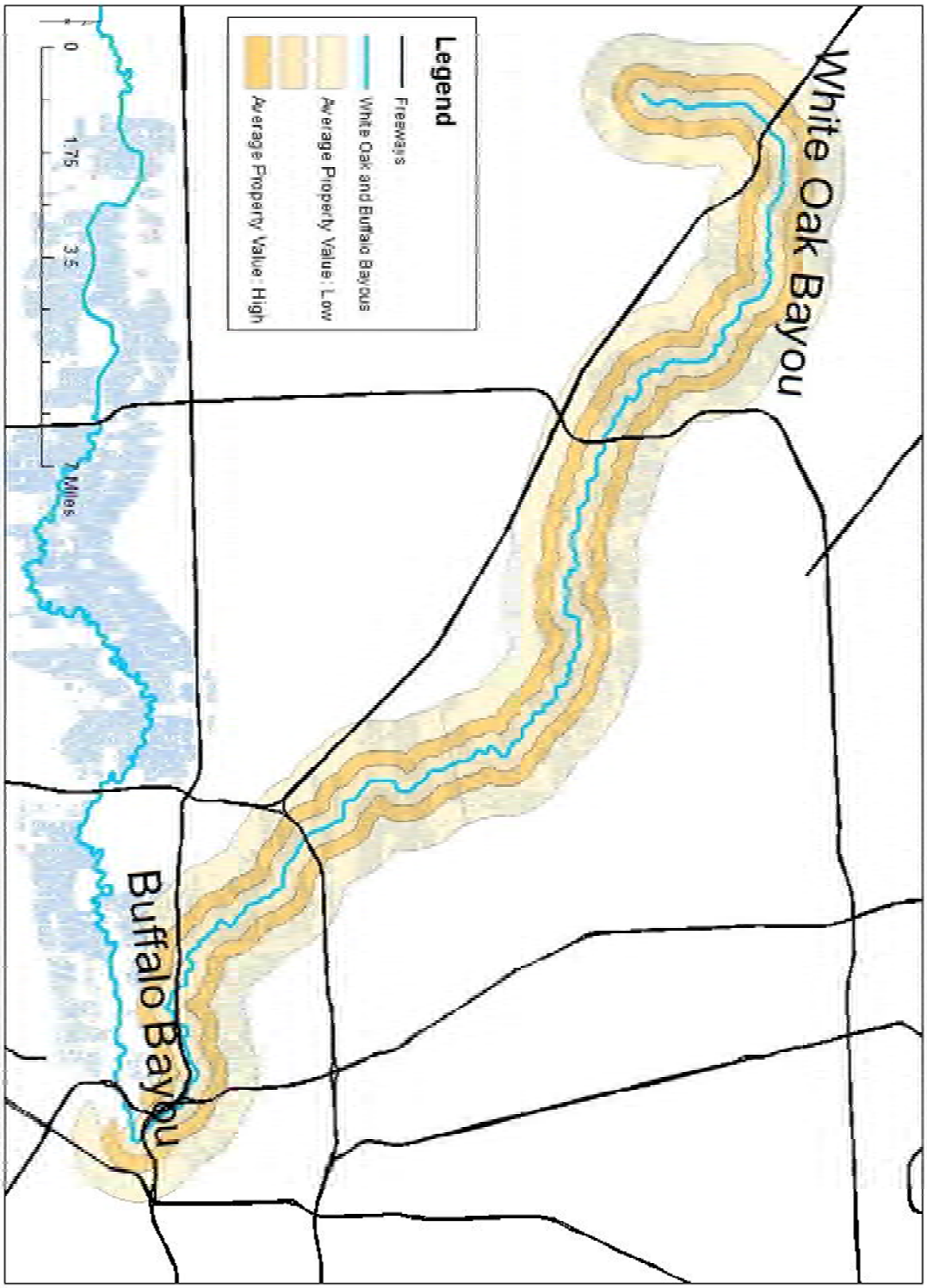
Figures courtesy of HCFCD (Hudson 2016). Values not adjusted for inflation.

Appendix C

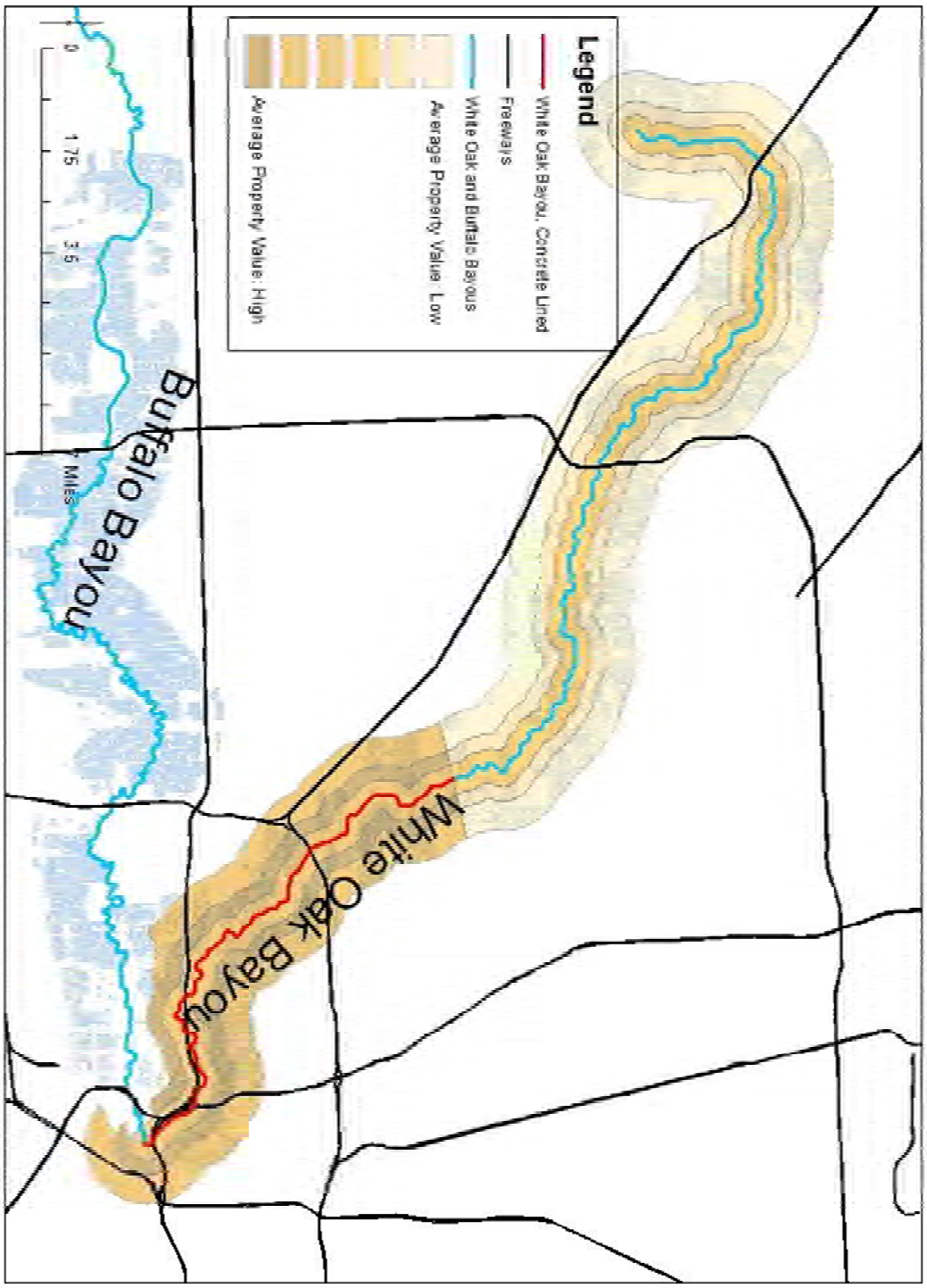
Single Family Residential Properties in the White Oak and Buffalo Bayou Watersheds



This image compares the values of residential properties near White Oak and Buffalo Bayous. Although property values increase as one approaches Buffalo Bayou, the same pattern is not replicated along White Oak Bayou.



This image provides a closer look at residential property values along White Oak Bayou. As one approaches the bayou, property values first rise in the .5 to .25 mile buffer, but then fall adjacent to the bayou.



When White Oak Bayou is divided into concrete-lined and non-concrete lined portions, real estate patterns change. While average property values along the channelized portion of the bayou display the same erratic pattern as was found along the whole of the bayou, average property values along the northern, more natural stream increase as one approaches the bayou.

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